SMAPVEX12

SMAP Validation Experiment 2012

Experimental Plan

Updated: February 8, 2012

Revision History

Revision	Date	Comments
v1	Nov 2, 2011	Draft v1 sent to SMAPVEX team
v2	Nov 14, 2011	Includes comments from S. Belair
v3	Nov 17, 2011	Includes vegetation protocols
V4	Nov 29, 2011	Includes description of in situ network
V5	Feb 8, 2012	Updated soil and veg protocols based on conference calls

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1. Introduction

1. 1 Project description

The Soil Moisture Active Passive (SMAP) mission will provide global soil moisture products that will facilitate new science and application areas, while extending those that have developed as a result of its predecessors. The breakthrough that SMAP will provide is significantly higher spatial resolution on a temporally frequent basis. This will be accomplished by integrating active and passive microwave remote sensing. Passive microwave remote sensing of soil moisture has a long history in soil moisture retrieval but faces limits on spatial resolution. Active microwave techniques can provide much higher spatial resolution data but there are challenges in developing a robust soil moisture retrieval algorithm. SMAP will exploit a combination of both techniques to produce an intermediate accuracy and spatial resolution product. In addition to this "flagship" product, SMAP will also provide a standard passive (radiometer-based) soil moisture product and a research active (radar-based) soil moisture product. Level 4 (combined satellite and model) profile soil moisture and carbon products will also be developed. A radar-based freeze-thaw product is also a standard mission product.

Validation of the suite of SMAP soil moisture and freeze/thaw products is a mission requirement. During the pre-launch phase of SMAP the major concerns related to validation are providing data for the development and evaluation of the SMAP algorithms and establishing the infrastructure to efficiently conduct the post-launch validation in a timely manner. Field campaigns are one of the methodologies that are used for these purposes. In addition to validation, these field campaigns can also be structured to support the development of the SMAP Applications Early Adopters projects.

The SMAP Project Science Definition Team (SDT) and the Cal/Val Working Group provide guidance to the Cal/Val activities of SMAP. As part of a recent SMAP Cal/Val Workshop (May, 2011), the SMAP Algorithm Teams were asked to provide an assessment of what outstanding issues could be addressed with a field campaign. This input was discussed and prioritized by the Workshop participants. Based upon the anticipated launch date of SMAP, it is critical that this campaign be conducted in 2012 in order for the algorithm teams to effectively utilize the results.

The baseline and option soil moisture retrieval algorithms based on radar and combined radar-radiometer measurements exploit the fact that SMAP revisits are at near the same look angle. This is due to the conical scan approach adopted by the instruments that share a common feed and rotating reflector antenna. Radar and radiometer measurements vary according to the soil dielectric constant, vegetation structure and surface soil roughness conditions. Given the varying time-scales associated with each of these factors and near-constant look-angle, the SMAP radar and radiometer measurements can be used to isolate the soil moisture signal. Time-series sequences of measurements need to be of long enough duration to isolate these factors. The purpose and design of SMAPVEX12 is to provide extended-duration measurements that exceed those of any past field experiments. This constitutes the unique and valuable attribute of this field campaign when compared with previous airborne experiments.

Furthermore the SMAP SDT and Algorithms Development Team (ADT) were provided with questionnaires and queries to prioritize the attributes of the pre-launch SMAP airborne field campaign. All of the soil moisture algorithms had two common requirements for a field campaign; an extended time series and diverse vegetation conditions. Data sets that supported the combined active passive algorithm were considered the top priority, which necessitates an aircraft instrument suite that will provide data to simulate the SMAP sensor system.

These requirements discussed above were used to design the SMAP Validation Experiment 2012 (SMAPVEX12). It was decided that SMAPVEX12 would focus only on the requirements for validation of the soil moisture algorithms and products. In response to requirements set out by the SMAP development teams, SMAPVEX12 will be designed such that data acquisitions capture variances in both soil and canopy water content including conditions during peak vegetation biomass. Consequently, the campaign will cover a period of approximately 6 weeks. The site will be located in an agricultural region south of Winnipeg, Manitoba (Canada) which consists of primarily annual cropland with some permanent grassland and mixed forest cover.

Separate field campaigns, taking place in Alaska in cooperation with the CARVE project, will focus on the freeze/thaw algorithm and product. It should be noted that the details provided below are still under discussion and development.

1.2 Canadian Objectives

Reducing risk to Canadians and enabling informed decision making, from individual decisions to government policy development, is supported by the availability of timely and accurate information. The impact of improved soil moisture monitoring extends to several areas of Canadian human and economic life and is of enormous value to Canadians. Timely, comprehensive and accurate soil moisture information leads to a better understanding of current and future weather, flood and drought risk, and better management of environmental and health issues. Improved monitoring and prediction of soil moisture conditions would provide critical information needed to reduce liability from climate related extremes and target programs towards areas where they are most needed. In the agricultural sector, limited access to spatially detailed and high quality data on soil moisture across Canada significantly impacts the ability to deliver programs and policies to mitigate and respond to risk. Access to accurate and temporally frequent soil moisture data improves response to drought/excess moisture conditions, assists in the development and delivery of water management strategies and agricultural best management practices. Access to spatially distributed surface soil moisture can improve numerical weather prediction and air quality monitoring through an improved characterization of land surface processes. In hydrology, better knowledge of soil moisture can improve model predictions of surface runoff and ground water recharge, enabling better prediction of water availability, transport of contaminants and flood prediction. These improved predictions will bring social, environmental and economic benefits to all Canadians.

The future SMAP mission is expected to become a critical source of improved soil moisture data for Canada. Consequently, the Canadian science community is engaged in pre-launch calibration and validation efforts to ready their operational program and policy counterparts to make full use of SMAP data and data products, once available.

In June of 2010, a first field campaign (the Canadian Experiment for Soil Moisture in 2010 or CanEx-SM10) was conducted over sites in Saskatchewan. This campaign supported Soil Moisture and Ocean Salinity (SMOS) validation activities as well as pre-launch validation and algorithm development for SMAP. Some science gaps remain to fully exploit the data, due primarily to the unusually wet conditions in this region of Canadian in the spring of 2010. These conditions led to a reduced variability in soil moisture conditions over space and time. As well, delayed seeding meant minimal crop presence during the 2010 campaign. Consequently, the effect of vegetation on the passive and active retrievals could not be properly assessed.

The overall objectives of the SMAPVEX12 campaign are essentially to gather additional observational data to support the development and validation of the SMAP active and passive soil moisture retrieval algorithms, to support validation of modeling and assimilation of SMAP data sets. These include finding ways to better mitigate low-level RFI effects observed in North America, improve the parameterization of vegetation (and its water content), inter-compare soil dielectric models, gather concurrent active and passive observations to establish relationships, gather SMAP-scale observations to validate all the algorithms, obtain relatively long time series for the radar-based algorithms, and improve transient water body detection.

In addition to supporting these overall SMAP goals, specific Canadian objectives include:

1. To acquire and process data over a Canadian landscape to assess models and algorithms used for retrieving SMAP data products (Level 2 and 3 surface soil moisture and Level 4 root zone soil moisture);

2. To evaluate the accuracy of alternate retrieval models currently used by the Canadian community, to estimate soil moisture from SMAP (Level 1) data;

3. To adapt models for retrieval of soil moisture from microwave brightness temperature and backscatter to the Canadian landscape (using Canadian land use and soils data bases, for example);

4. To evaluate new approaches used in the land data assimilation systems to combine passive and active L-band data for soil moisture analysis (Level 4);

5. To assess the improvement in the representation of the energy, water, and carbon cycles in Canadian environmental analysis and prediction systems using active-passive data;

6. To familiarize operational program and policy users with passive and active soil moisture products, to prepare these users for exploitation and assimilation of SMAP products, once available, and for these users to provide feedback on the suitability of SMAP products for their activities.

7. To train highly qualified personnel (HQP); and

8. To develop, expand and strengthen partnerships between the Canadian and U.S. soil moisture communities.

SMAPVEX is designed to contribute directly to the objectives described in the “Canadian Science and Applications Plan for the Soil Moisture Active and Passive Mission” (August 2011). Specifically, this experiment will assist with Canadian contributions to pre-launch cal/val for soil moisture products. The SMAPVEX site is one of the core Canadian validation sites for SMAP, described in the Canadian SMAP plan.

2. Study Site

To support the overall SMAP calibration/validation objectives, as well as those specific to the Canadian team, an agricultural domain with a range of crop types and some forest and grasslands was desired. In order to address the algorithm requirements, significant change in the vegetation water content over the study period is required (approximately 45 days).

Another element in the field campaign is the partnership of SMAP with the Canadian Space Agency (CSA). One of the major elements of this cooperation is the CSA support of validation activities, as well as its own applications projects. Initial discussions between the SMAP Cal/Val Team and Canadian scientists involved in SMAP led to a suggested site in the Red River Watershed of southern Manitoba. This region provides the desired mix of land covers and is being developed as a long-term in situ soil moisture network.

2. 1 General Description

Agriculture and Agri-Food Canada (AAFC), through the Growing Forward policy framework, is funding a Sustainable Agriculture Environment Systems (SAGES) project to develop a soil moisture monitoring capability to support the Canadian agriculture sector. The project encompasses not only the science, through AAFC's Research Branch, but also establishment of service delivery through the Agri-Environmental Services Branch of the department.

The SAGES implementation site selected is the Canadian Red River Watershed (figure 1). This is a watershed of extremes in soil moisture. For example, according to the 2008-2009 Annual Report from the Manitoba Agricultural Services Corporation drought and excessive heat have historically (1960-2007) accounted for 37% of reported crop losses, while excessive moisture was responsible for 36% of losses. The watershed is characterized largely by agricultural land use with a wide range of crop and soil conditions. Crops include forage, pasture, canola, flaxseed, sunflower, soybean, corn, barley, spring wheat, winter wheat, rye, oats, canary seed, potatoes, and field peas. The typical crop rotation is a cereal crop alternating with oilseed\pulse crops. Typical field sizes range from 20-30 to 50-60 hectares. Annual crop type mapping for the entire Red River Watershed, via remote sensing techniques, is completed by AAFC's Agri-Environmental Services Branch. It is also important to note that this is a shared watershed with the U.S. Three-quarters of the Red River Watershed lies on the U.S. side of the border.

In situ instrumentation of the watershed will occur incrementally, with respect to the geographic coverage of the network and the number of network stations. Initially a single sub-watershed has been selected based on geostatistical analysis of soil texture and derived soil variables for all of the Red River sub-watersheds. The watershed selected, the Brunkild sub-watershed, has an excellent contrast in soil properties from west (fine clay soils) to east (coarser and better drained soils). The Brunkild watershed is approximately 60 km (east-west) by 10 km (north-south). The Brunkild sub-watershed, as well as the larger Red River Watershed, is one of the GEO Joint Experiment on Crop Assessment and Monitoring (JECAM) international super sites.

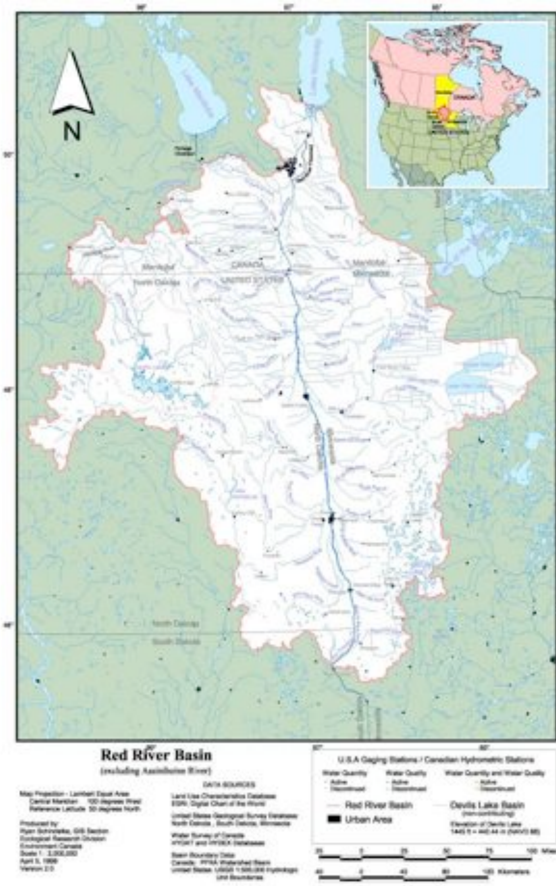

Figure 1. Extent of the Red River Watershed.
Approximately 25% of the watershed falls within Canada, with the remainder of the watershed residing within Minnesota, North Dakota and South Dakota, U.S.A

2.2 Intensive Sample Site Description

(description to follow once team has selected site – Brunkild, or secondary site)

2.3 Overview of In Situ soil moisture networks

Several soil moisture networks are present in the agricultural regions of southern Manitoba run by the University of Manitoba, Agriculture and Agri-Food Canada and Manitoba Agriculture, Food and Rural Initiatives (MAFRI). The AAFC network covers a small area in and around the Brunkild sub-watershed, whereas the University of Manitoba sites are more geographical dispersed (figure 2).

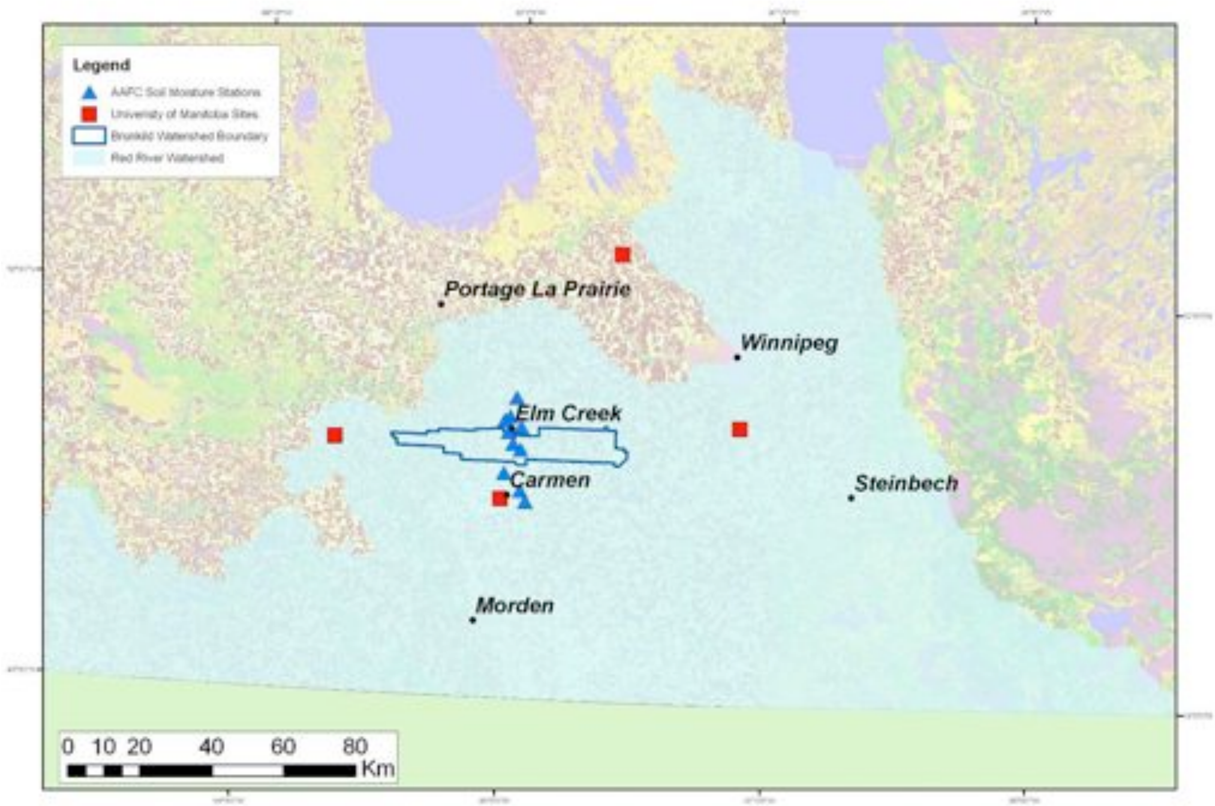

Figure 2. Location of Manitoba in situ soil moisture sensors within the Canadian portion of the Red River watershed.

In 2011, Agriculture and Agri-Food Canada (AAFC) began piloting an in situ soil moisture monitoring network in and around the Brunkild watershed. The network was established to provide a direct source of near-real time information on soil moisture conditions in an agriculturally risk-prone watershed, and to provide a data set that can be used holistically with remotely-sensed and modelled data products for calibration and validation of models. The network was designed to capture the maximum soil variability within the Red River watershed, with the specific location of the sensors established along a gradient is soil texture classes (figure 3). The network consists of nine in situ monitoring stations distributed proportionally to be representative of the different soil texture classes. Sites were selected based on soil texture variability, willingness to cooperate from local producers and soil survey by regional soil experts. Each station measures soil moisture, soil temperature and liquid precipitation, with triplicate measurements of the soil moisture and soil dielectric at each depth, and duplicate measurements of soil temperature. This redundancy was applied to ensure critical variables would continue to be captured in the event of sensor failure, and to provide an indication of the within site variability in moisture conditions. Soil moisture and temperature are measured horizontally at depths of 5, 20, 50 and 100 cm, with an additional three probes place vertically at the surface to capture integrated surface soil moisture over a 6cm depth (figure 4). Each site is instrumented with Stephen's Hydra Probes and a tipping bucket rain gauge (Campbell Scientific 700) powered by solar panels and batteries (figure 5). Data is logged using an Adcon A755 telemetry unit which transmits measurements to a base station in Ottawa, Ontario at 30 minute intervals. Measurements are collected on a 30 minute time scale for all variables, which include soil moisture percentage (using Stephen's default dielectric conversion model), soil temperature in Celsius and real soil dielectric permittivity. All AAFC sites are located within or on the edge of cultivated agricultural fields, with the system set up to capture data (when valid) year round without removal of equipment required due to land management activities. During installation, soil cores were collected at the location of each probe installation and preserved for soil moisture dry down calculation and soil texture and bulk density analysis. Site specific soil moisture dielectric conversion models will be developed by using soil moisture and dielectric values calculated using a dry down process in a laboratory. These will be applied to each sensor to obtain higher accuracy soil moisture values.

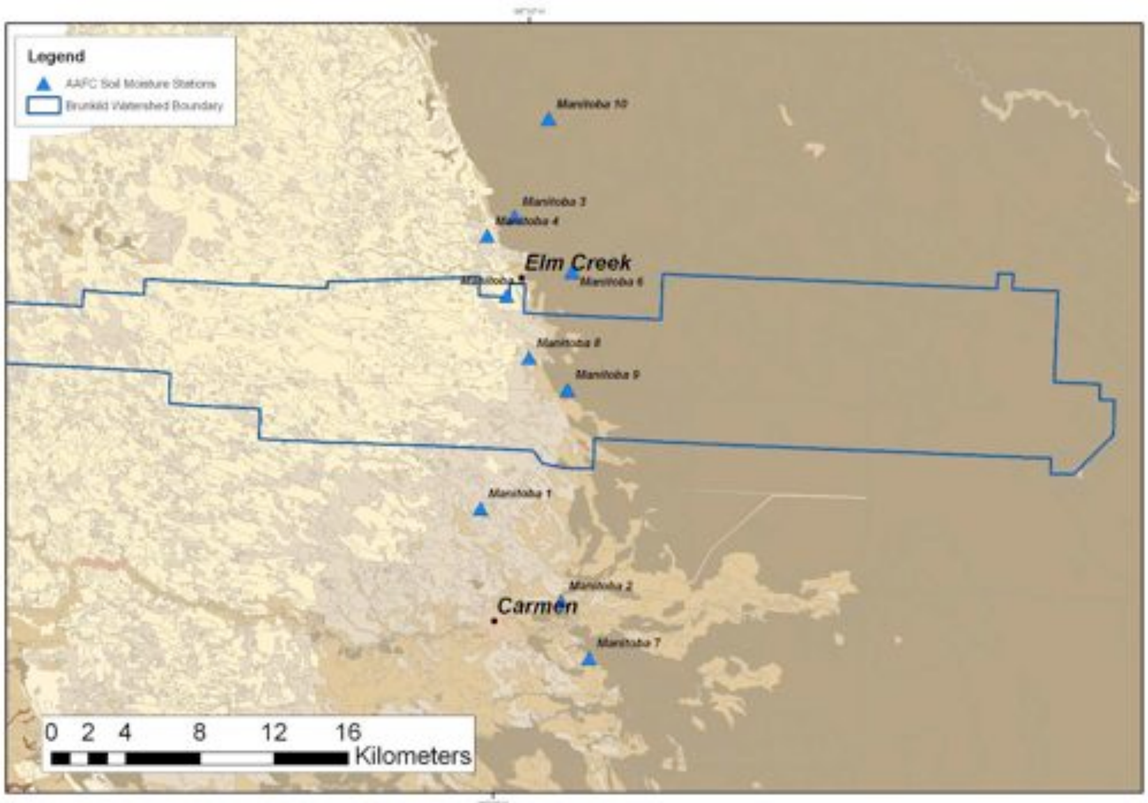

Figure 3. Location of the AAFC Manitoba in situ soil moisture network.
Backdrop image shows clay dominated soils on the eastern portion of the watershed and sandier soils on the western portion of the watershed.

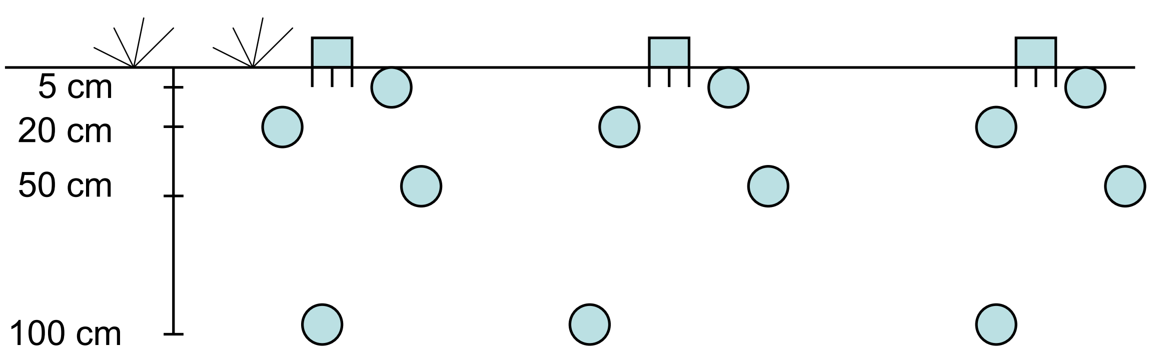

Figure 4. Schematic of probe location within each soil pit for AAFC in situ monitoring sites.

Figure 5. Site installation for AAFC in situ soil moisture sites**.**

As part of this soil moisture piloting, advances in wireless communications technology are being assessed through a sensor web approach. Sensor webs integrate three aspects: sensing, communication and computing. This approach seeks to create networks that can capture and distribute data in near real time and work interoperably with other networks to create a ‘network of networks’. This approach can maximize scarce resources to optimize collection of critical agricultural variables. For this pilot, wireless communications are being piloted through the use of remote telemetry units (RTUs) equipped with subscriber identity module (SIM) cards to collect the data and communicate this to a centralized data base for quality control processing. Options for open geospatial dissemination of the data via various web-based platforms are being explored. Data will be disseminated publicly once a data quality control assessment has been made.

The University of Manitoba soil moisture network is run by Dr. Paul Bullock of the Department of Soil Science. This network consists of five in situ soil moisture stations (one dormant) with associated meteorological station equipment (figure 6). Stations were installed in the spring of 2009 and 2010 in both cropland and pasture sites. Data are collected via Campbell data loggers and are manually downloaded for use in academic research.

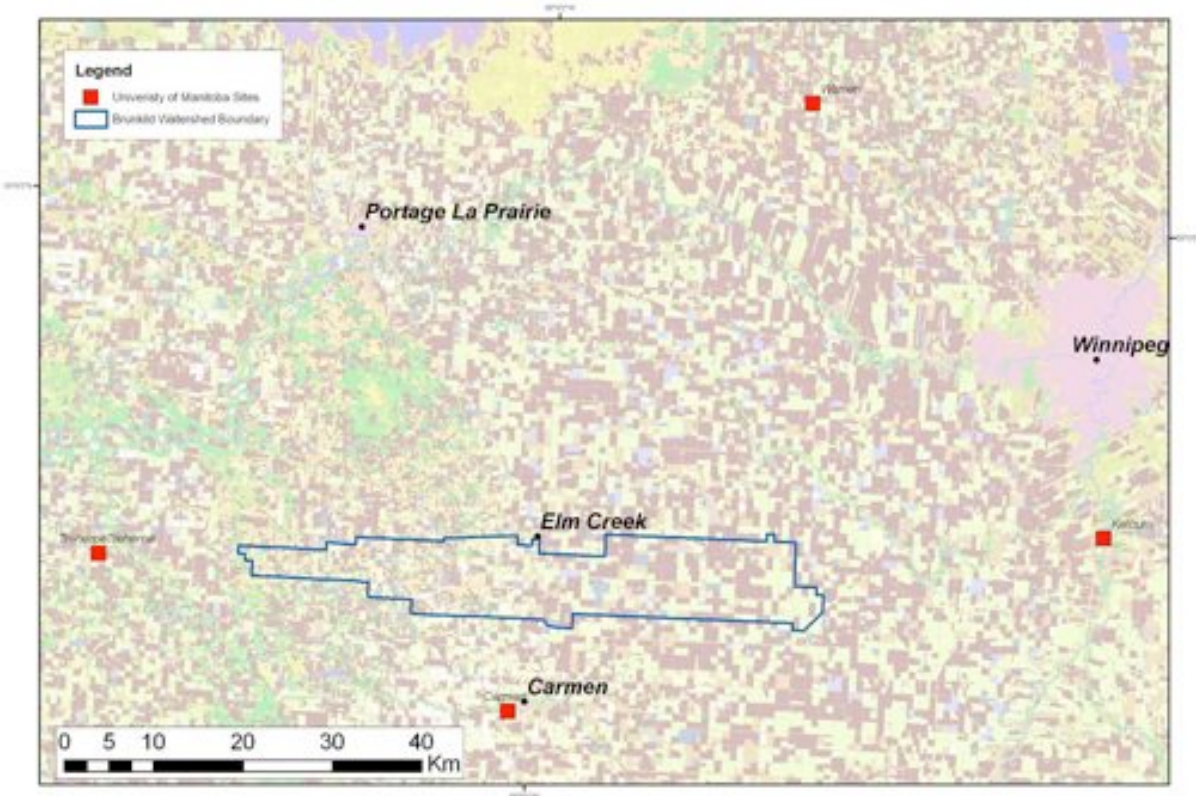

Figure 6. Location of the University of Manitoba in situ soil moisture monitoring sites and meteorological stations.

The MAFRI Ag Weather program supports soil moisture collection through the University of Manitoba stations as well as through a gravimetric survey of soil moisture conditions across the agricultural regions of the province during the last week of October of each year. This survey was started in 2004 and collects auger samples from 0-15 cm, 15-30 cm, 30-60 cm, 60-90 cm and 90-120 cm. These are weighed and oven dried and matched against a soil properties database of bulk density, wilting point, field capacity and available water holding capacity to obtain measures of available soil moisture (mm) and percent available water holding capacity for root zone (0 – 120 cm), top zone (0 to 30 cm) and sub zone (30 – 120 cm). The locations of these sample points for the Red River watershed are given in figure 7.

Figure 7. Location of MAFRI fall gravimetric soil moisture survey sampling

2.4 Availability of Other Supporting Data (met stations, soils data, digital elevation data, land cover/use etc.)

Several meteorological stations are located within the agricultural regions of Manitoba, established through provincial government agencies such as MAFRI and Manitoba Water Stewardship, the University of Manitoba, federal government agencies such as AAFC and Environment Canada and private companies such as Weather Farm, Weather Bug and Weather Innovations (figure 8). Most stations record typical meteorological variables including air temperature, total precipitation, wind speed and relative humidity, with some having additional data on net radiation, snow accumulation and soil temperature. Data from Environment Canada can be downloaded station by station from their website (http://climate.weatheroffice.gc.ca/climateData/canada_e.html). Data from AAFC networks are distributed internally within AAFC. Current conditions data from MAFRI stations can be displayed on the MAFRI website (http://tgs.gov.mb.ca/climate/CurrentConditions.aspx). Note that many stations are shared between the University of Manitoba, MAFRI, AAFC and EC. Private weather networks are available through a subscription service (see figure 9 for example).

Figure 8. Location of AAFC, EC and MAFRI meteorological stations.

Figure 9. Location of Weather Innovation (WIN) meteorological stations supported by the Manitoba Potato Growers Association.

Carbon flux measurements are potentially available through individual research stations in the area. A portable carbon flux tower will be made available for the duration of the 2012 SMAPVEX campaign through AAFC and Environment Canada.

Digital elevation model (DEM) data for the area is available from a number of sources. The Canadian Digital Elevation Data (CDED) is available at 23 and 93 m spatial resolution and 10m vertical accuracy for the 23m data set and can be downloaded freely from Natural Resources Canada's GeoBase system (www.geobase.ca). The DEM from the ASTER Global-DEM project is available at a 30m spatial resolution with a 7-14m vertical accuracy (figure 10). Coarser resolution DEMs are available from the Shuttle Radar Topography Mission (SRTM) at 90m spatial resolution and 10m vertical accuracy.

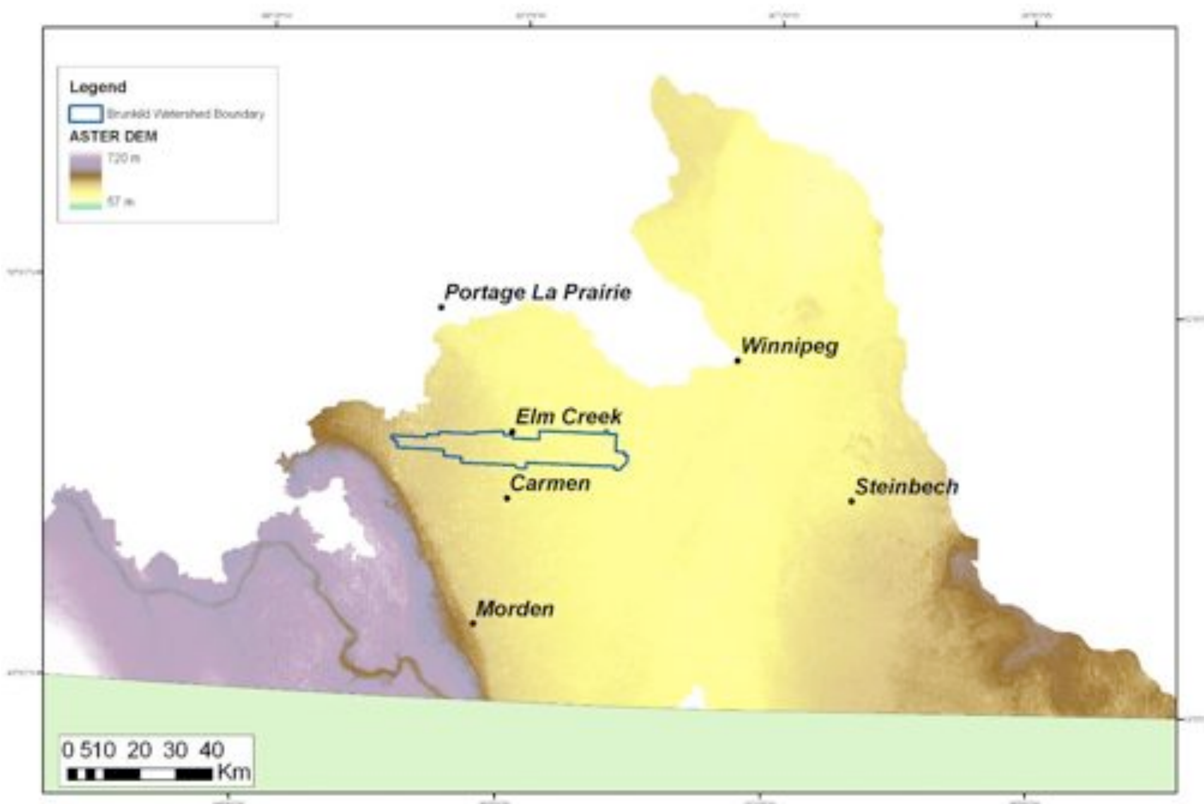

Figure 10. Digital Elevation Model data from the ASTER GDEM project for the Red River Watershed

Soils data for the area are available from the AAFC Soil Landscapes of Canada (SLC) polygon data set. These are based on soil and topographic survey compiles at a 1:1 million scale. Each soil polygon may contain one or more distinct soil landscape components. Each SLC polygon contains information for each horizon on horizon depth, soil texture, soil organic carbon, pH, base saturation, cation exchange capacity, saturated hydraulic conductivity, water retention at saturation, field capacity and wilting point, bulk density, electrical conductivity, calcium carbonate equivalent and decomposition (Von Post). Information on landscape position (slope, aspect), soil drainage class, parent material, and soil classification are also provided for each polygon. These data are currently available through the Canadian Soil Information Service (CanSIS) via AAFC Agri-Geomatics. Work is currently being done to convert key soil attribute data from the SLC polygons to a raster data set to facilitate integration into modeling activities. Provincial soil surveys are available at higher spatial resolutions for selected areas within the province.

Land cover data are available for circa 2000 at a 30m resolution derived from Landsat-TM data for the agricultural extent of the province through the AAFC Earth Observation Service. This land cover data set provides an indication of annual and perennial agricultural land, as well as native grassland, forest, wetland and urban areas within the agricultural extent. National land cover data derived from this data set and others from the forested and northern regions is available on a polygon basis through GeoBase (http://www.geobase.ca/geobase/en/data/landcover/index.html). Annual crop type maps are available for Manitoba from the AAFC Earth Observation Service at a 50 m spatial resolution, classifying cropland into specific crop classes for each growing season (figure 11). This data set is available for 2008, 2009 and 2011 (2010 was not completed due to a lack of ground truth data to support the classification). These maps are derived based on a combination of optical and radar data collected throughout the growing season and use a supervised decision tree classifier to obtain the final maps. Maps for a typical growing season are completed in the late fall for each year.

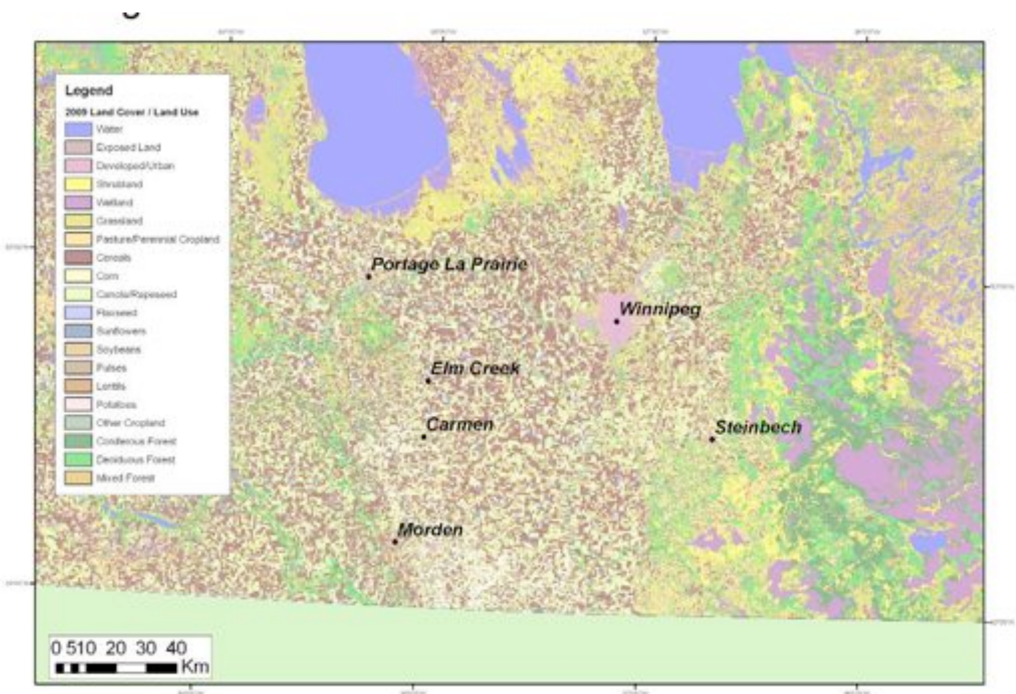

Figure 11. Agricultural land cover/land use for Red River Watershed

2.5 Selected Sampling Fields

(to be completed once intensive sample site is selected)

3. Description of measurement instruments

3.1. Ground instruments specifications

Ground measurements during the campaign will be made continuously through in situ network stations discussed above, as well as through in field measurements made intensively by field crews during the SMAPVEX campaign.

3.1.1. Hydra Probe II, theta probe, profilometer, etc…

Field measurements of soil moisture will be made using portable Stephen's Hydra probes identical to the ones used in the AAFC in situ network. These probes are based on coaxial impedance dielectric reflectrometry and use an oscillator to generate an electromagnetic signal at 50 MHz that is propagated through three metal tines into the soil. The part of the signal that is reflected back to the unit is measured in volts and is used to solve numerically Maxwell's equations to calculate the impedance and the real and imaginary dielectric permittivities. Real dielectric permittivity can be related to soil moisture using empirical relationships between dielectric and moisture or using physically based dielectric mixing models. Instantaneous measurements can be acquired over a 6 cm depth from the surface when the probe in inserted vertically. A default soil dielectric conversion model is applied based on soil texture classes, with an accuracy of +/- 3% volumetric soil moisture. Improved calibration of instrument soil moisture can me made using site specific texture information, custom calibration models calculated using a laboratory experiment or reference to gravimetric soil moisture samples collected periodically during the field campaign.

Alternative instruments that can be used for instantaneous soil moisture measurements are the Delta-T Theta probes. These probes operate on a similar impedance technology to the Hydra Probes using a 100 MHz frequency through four tines that are inserted into the soil. Soil moisture is calculated empirically using a model developed by Miller and Gaskin for an accuracy of +/- 5% volumetric soil moisture.

Soil roughness measurements can be made using a portable pin profilometer (figure 12) that uses surface displacement and post processing techniques to obtain root mean square roughness (rms) and roughness correlation length. These devices are custom built using metal pins with tips coated in red material, a wooden board painted white, a set of legs to support the board and a mechanism to release pins for surface displacement. A retractable metal bar can be mounted to the board to hold a standard digital camera to take a picture of the roughness profile once it is in place. Boards are typically 1 to 2 m in length and typically three measurements are made side by side to capture a longer roughness profile. Roughness measurements can be made to capture oriented surface roughness (perpendicular to tillage structure in agricultural fields) or sensor specific roughness by aligning the profilometer perpendicular to the look direction of the microwave sensor. Photos obtained in the field can be post-processed using a Matlab routine to obtain the roughness parameters.


Figure 12. Capturing surface roughness with the roughness profilometer.

The Crop Scan instrument is a multi-spectral optical radiometer that measures reflected solar radiation from the crop canopy. The instrument is mounted on a pole and held above the canopy to collect nadir views of reflected solar radiation at spectral bands defined by the instrument model and the filters used. The radiometer has both upward and downward sensors to capture incoming solar radiation to the sensor as well as the energy reflected from the canopy. Measurements must be taken in full sun, ideally within 2 hours of solar noon.

3.1.2. Inventory of ground instruments and laboratory facilities

Table 1 provides a listing of major equipment required for SMAPVEX. The table also indicates contributions to this equipment by the SMAPVEX team.

Table 1. List of ground instruments available for SMAPVEX

Equipment	AAFC	Université Sherbrooke	University of Guelph	EC	Other
Hand held Hydra Probe	4 Pogos	1 Pogo	5 Pogos	6 with data loggers	
Theta probes (as a backup)	14				
Cropscan	1		1		1 (JPL)
Metris TN400L Professional Grade Infrared Thermometer	10				
Taylor® Switchable Digital Pocket Thermometer	20				
GPS units	10	2	10		
LAI camera + FishEye lense	3				
Cameras	9	2	2		
Bulk density samplers		2	several		
Roughness pin profiler with mounted camera		2	1		
Balance - soils	1				
Balance - biomass					
Drying ovens for soils	3				
Drying ovens/rooms for vegetation	facilities in Portage la Prairie				

3.2. Aircraft instruments

(To be updated by Tom; need to add Pals description)

3.2.1 NASA G-II and UAVSAR

The Uninhabited Aerial Vehicle Synthetic Aperture Radar (UAVSAR) is an aircraft based fully polarimetric L-band radar that is also capable of interferometry. It is currently implemented on a NASA Gulfstream-III aircraft (http://uavsar.jpl.nasa.gov/). Details on the UAVSAR are listed in table 2.

Table 2. Description of the UAVSAR

Instrument	**Uninhabited Aerial Vehicle Synthetic Aperture Radar (UAVSAR)**
Owner	NASA/JPL/Dryden (USA)
Platform	Gulfstream III; operating altitude up to 13 km
Frequencies	L-band (1.26 GHz)
Polarizations	HH, HV, VH, VV
Spatial Resolution	80 MHz Bandwidth, 1.66 m range x .8 m azimuth SLC 3 m multi-looked (6 looks)
Scan Type	SAR with Electronically scanned active array, range swath ~20 km looking left of track between 25 and 65 degrees.
Antenna Type	Phased Array

For SMAPVEX12, the nominal flight altitude is 13 km and the aircraft speed is 220 m/s. UAVSAR looks to the left of flight direction and collects data over a swath between 25 and 65 degrees, which is a nominal swath of 21 km. The most relevant portion of the data swath for SMAP, which has an incidence angle of 40 degrees, will be data collected between ~35 and 45 degrees, which is a narrower swath of ~3.8 km.

3.2.2 Satellite Instruments

The technical characteristics of satellites to be programmed for SMAPVEX12 are summarized in table 3. For detailed descriptions, the reader is referred to SMOS, AMSR-E, WindSAT and RADARSAT-2 web sites.

Table 3. Technical characteristics of satellite instruments

System	Satellites	Frequency (GHz)	Polarization	Incidence angle (^{o})	Resolution
Passive	SMOS	1.4	H and V	0 -55	30 km
	WindSAT	6.8, 10.7, 18.7, 23.8, 37.0	H and V	54	10 to 55 km
	AMSR-E	6.9, 10.7, 18.7, 23.8, 36.5, and 89	H and V	55	5.4 to 56 km
Active	RADARSAT-2	5.4	Single: HH Dual: HH, HV Quad Pol: HH, HV, VH, HV (plus phase)	20-49	3-100 m
	Envisat ASAR	5.4	Single: HH Dual: HH, HV Wide: HH or VV	15-45	30-150 m
Multi-spectral	SPOT-4/5				10, 20 m
	Landsat				30 m
	AWiFS				56 m (at nadir)
	RapidEye				6.5 m

4. Data acquisition

4. 1. Experiments

4.1.1. Calendar of data acquisition

(To be completed)

4.1.2. Ground-based measurement strategies

4.1.2.1 Soil physical properties

The following soil physical (SP) properties will be measured during SMAPVEX12:

SP1: Soil Moisture
SP2: Soil Temperature
SP3: Soil Bulk Density and Texture

SP 1. Soil Moisture

Objective: Surface soil moisture will be measured at the SMAP scale to assess passive and active radar retrieval approaches and to assess field-scale variability in soil moisture to assist in scaling issues. The overall goal of the soil moisture sampling should be to maximize the number of fields from which representative field-scale soil moisture determinations can be acquired.

Measurement approach for agricultural fields:
Surface soil moisture measurements will be acquired over selected agricultural fields coincident in time to flight overpasses. Field crews will use hand-held probes to measure moisture at near surface depths (6 cm) at multiple locations in each field.

Each crew will consist of 2 members, both outfitted in a manner illustrated in figure 13, to facilitate soil moisture measurements being recorded electronically and hard copy by both persons. Each crew will be given 5 fields to sample in a prioritized order. The crew members will work simultaneously on each field following a prescribed pattern of sample locations and a specific sampling protocol at each sample point.

Sixty fields were sampled during CanEX-SM10. With 20 field samplers working as ten 2-person teams for SMAPVEX-2012, the actual number of fields sampled is estimated to be between 40 (near peak crop biomass) and 50 (with low crop biomass).

Figure 13. Illustration of a soil moisture sampler with a holder.
This setup will facilitate the capture of surface soil moisture with a hydraprobe and recording each reading electronically and hard copy.

In addition to the surface soil moisture collected by field crews, soil moisture at discrete depths down to rooting zones will be acquired by in situ network stations. The location and data collected by these stations is described in previous sections of this document.

Flight overpass sampling strategy for agricultural fields:

CanEX-SM10
For each of the sixty sample fields, moisture measurements were acquired along two parallel transects. These transects were placed 400 m apart, with 7 sites located along each transect (figure 14). Sample sites will be spaced 100 m apart along each transect. These transects which were completed over mostly bare fields required approximately 45 minutes per field. The sampling teams were able to access approximately 5 fields per day.

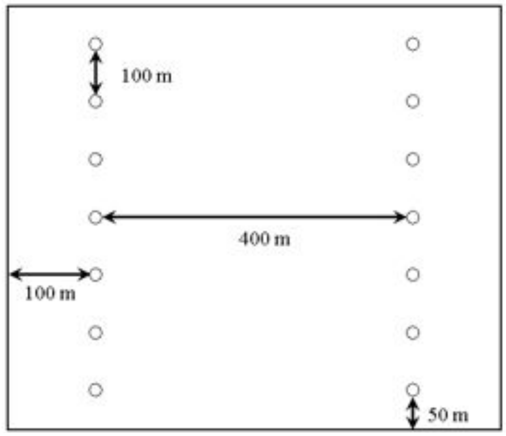

Figure 14. Diagram of soil moisture sampling strategy for CanEX-SM10.
14 points over 800 m x 800 m, 2 transects 400 m spacing with 7 points at 100 m intervals (not to scale).

Alternative for SMAPVEX-2012

Over the Manitoba study sites, agricultural fields are often a quarter-section in size (160 acres) with dimensions of 0.5 miles by 0.5 miles. The legal survey system normally provides some type of road access on two perpendicular sides of quarter section fields. The following sampling pattern is meant to facilitate access to sampling locations and reduce walking time back to the vehicle.

There will be 16 sampling points in each field arranged as two parallel transects, one at 100 m from the road and the other another 200 m further into the field. The transects should be oriented parallel to the seed row direction to make it easier to walk between points. The end points of each transect will be 100 m from the field edge. Sampling points along each transect will be 75 m apart. Both team members will drive in their vehicle to the entry point along the road and will enter the field at the mid-point of the transects. One sampler will take measurements of the 4 sample points at one end of the first transect, move 200 m to the end of the 2nd transect and sample the 4 points at the end by moving back toward the middle. The second sampler will sample the other points in the transects following a mirror-image pattern. The samplers should meet back in the middle of the 2nd transect and exit the field together at the entry point alongside their vehicle (see figure 15).

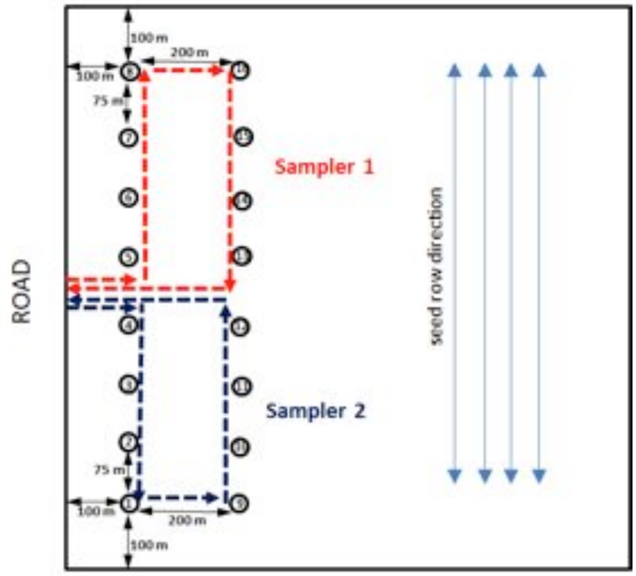

Figure 15. Soil moisture sampling strategy for SMAPVEX

Surface Soil Moisture Sampling Protocol
All sample points will be loaded into handheld GPSs to allow easy navigation to the sample site. This will be particularly important in fully developed canopies where navigation can be difficult and flags are often lost as the crop grows. To avoid confusion, data labeling will be standardized as follows

Field # - Site # - Replicate #

Soil moisture measurements will be stored in the handheld probe data logger, and will also be written onto data sheets.

Agricultural fields in the area are annually cropped and seeded in rows, mainly in the spring or sometimes in the fall. Depending on the seeding equipment, crop rows are separated by 15 to 35 cm for most crops to wider spacings for the row-seeded crops such as corn or soybeans. The rows are normally along the top of a small ridge of soil created by the seeding equipment with the inter-rows at the bottom of the ridge. In some cases, the rows may not be as clearly defined such as behind air-seeding equipment using sweep openers that spread seed across 3 to 4 inches within each row. In these fields, the rows can be more difficult to discern, especially when the crop has reached biomass and the canopy has closed.

At each sample location, a total of 3 readings will be taken with the 1st reading between the crop plants at the top of a ridge, the 2nd reading in the middle of a ridge and the 3rd reading at the bottom of a ridge (figure 16). If there are no discernible ridges, all the readings will be taken and a note made on the sampling sheet that there were no ridges. Always insert the probe perpendicular to the soil surface as shown in the figure below.

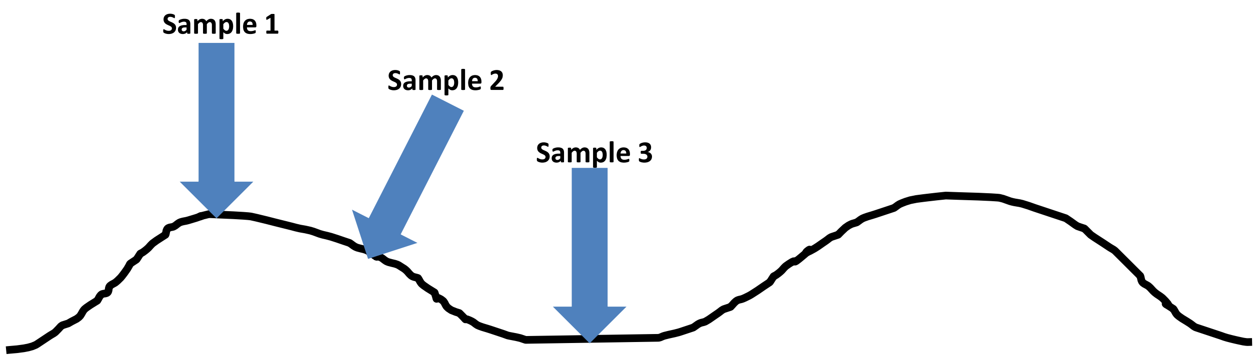

Figure 16. Location of replicate soil moisture measurements at each site

Each sample location will avoid large cracks or dry clods or areas that have been heavily compacted by tractor wheels. Samplers must take care not to push the moisture probe in too far and cause compaction, especially if the soil is loose.

Each crew will be assigned 5 fields to sample and they should be sampled in order (from 1 to 5). The first four fields are "priority fields" (i.e. they must be sampled if accessible) with the 5th field is an option if there is time. The goal is to ensure a subset of fields have a complete time series of surface soil moisture samples throughout the SMAPVEX-2012 campaign. Currently, with about 20 samplers (ten 2-person crews) this strategy would ensure that at least 40 fields have a complete time series of surface soil moisture samples for each date of sampling.

Measurement approach for forest sites:

During the CanEX-SM10 the sampling protocol for forested sites involved three measurements sites at each sampling region (i.e. location where the vehicle was parked) with three replicates at each site (9 soil moisture measurements total). A similar type of sampling protocol is suggested for the SMAPVEX12 campaign.

During CanEX-SM10 forest sampling was conducted off of the road network and the site accessed by entering the forest canopy 25 metres perpendicular to the road. The next two sampling locations were found 10 metres away from the first site again walking perpendicular to the road). The sampling protocol for each site involved the measurement of volumetric soil water content, soil bulk density and collection of the leaf litter or organic soil layer.

To collect the organic layer, a rectangular grid (in this case a picture frame) measuring 21.59cm by 27.95cm was laid over the ground. Measurements of the organic layer depth were recorded from each corner of the picture frame. The organic layer (leaf litter and organic soil if present) were scraped from the mineral soil layer and placed in a labeled zip-locked bag (site and sample number) for subsequent oven drying and calculation of the volumetric water content.

Within the scraped region, three measurements of the soil volumetric water content were performed using the Hydra probe instrument. Finally a single bulk density sample (as described below) was taken from the now exposed mineral soil. The bulk density sample was also placed in a labeled zip-locked bag for weighing and oven drying for calculation of volumetric water content.

Intensive sampling strategy:

The intensive soil moisture sampling services a number of objectives. The intensive sampling provides the data to relate time series measurements to field averages. These data would also permit scaling of the 13 (or 26) point samples to a scale that would allow radar soil moisture retrievals to be related to SMOS data. More intensive measurements also provide the data necessary to evaluate variability in soil moisture within an area equivalent to a RADARSAT-2 standard mode (30 m) pixel. If intensive sampling is undertaken, it will be conducted on a limited number of fields which means that on intensive sampling dates, the opportunity to collect field-scale data on a larger number of fields will be lost.

Two intensive sampling days will be targeted (one in the morning and one in the afternoon). The number of fields surveyed during these two days will be dictated by the number of available field personnel. The intensive sampling will be targeted to the latter part of the sampling campaign when crops have matured and dried, so that the variation in soil moisture will be a more significant factor affecting the microwave signatures. Some fields may even be harvested by this stage of the campaign. These fields should be selected if they fit the criteria because after harvest, the ability to move between sample locations within the field will be greatly enhanced. The time required to intensively sample a field will vary greatly depending on the type of crop, the stage of crop development and whether or not the field has been harvested. It may take an entire day for a single crew to intensively sample one field. The selection of fields will concentrate on those fields with time series data and will be chosen to reflect the variability within the crop mix that is representative of the area.

Intensive sampling days: The intensive sampling days will address the scaling objective related directly to the time series data as well as assist with relating the radar soil moisture retrievals to the soil moisture estimation from SMAP data. Both a 50 m grid of 49 sampling points and a 100 m grid of 40 sampling points will be nested within the intersection of the main sample grid (see below). The two grids will share common sampling locations, so that in total there will be 73 samples collected to fill out the two grids. The sample locations will minimize the distance from the road access on the two accessible sides of the field.

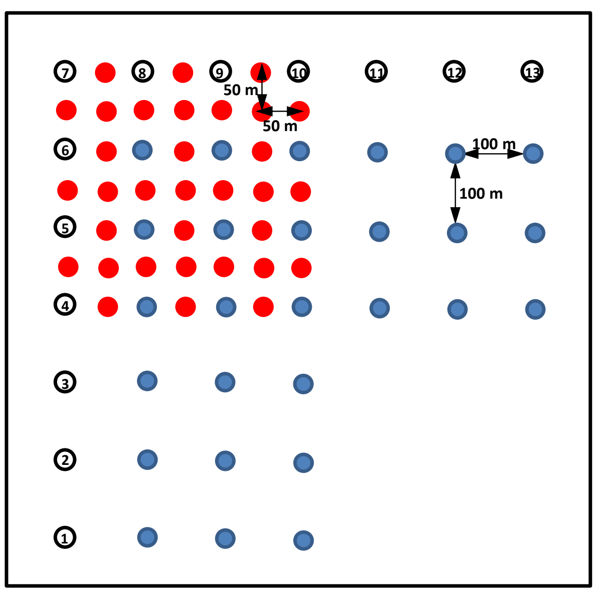

Figure 17. Strategy for intensive soil moisture sampling

Table 4. Summary of soil moisture collection strategies

	Flight overpass sampling	Intensive sampling
sample sites per field	16	73
transects per field (distance between transects)	2 (200 m)	7 (100 m); 7 (50 m)
sites per transect	8	7
distance between sites	100 m	100 m; 50 m
replicates per site	3 (top of ridge, middle of ridge, bottom of ridge)	
measurement depth	6 cm	

SP 2. Soil and Vegetation Temperature

Measurement approach:
Soil temperatures will be recorded using a simple digital pocket thermometer. For each sample field, four sites will be selected to measure soil temperature (table 5). The digital thermometer will be inserted to two depths – 5 cm and 10 cm. These depths will be indicated on the thermometer to facilitate insertion to the correct depth. Temperatures will be recorded on data sheets. At these same 4 sites, surface temperatures for soil and vegetation will be measured using a thermal infrared thermometer. Temperatures will be recorded for sunlit vegetation and sunlit soil, as well as for shaded vegetation and shaded soil. These measurements will also be recorded on data sheets.

Table 5. Summary of temperature and bulk density sampling strategies

Property	Number of sites per field	Depth	Instrument	Description of approach
Soil Temperature	4	5 and 10 cm	Digital pocket thermometer	insert to 5 cm, take reading then push to 10 cm, take reading
Soil and Vegetation Temperature	4	Surface	Thermal infrared thermometer	measure sunlit soil, sunlit vegetation, shaded soil, shaded vegetation
Bulk Density	2 (1 for each team member)	5.6 cm	Soil core	2 core samples; 3 probe readings within 15 cm of core
Site Photos			Digital camera	one taken parallel to row direction; also take photo of field ID, date, time and direction

SP3: Soil Bulk Density and Texture

Objective: To provide data to calibrate the soil moisture measured by the hand-held moisture probes over a range of soil moisture conditions and for all fields. These measures will be particularly important if both the theta probe and hydra probe sampling equipment is used during the experiment. Calibration of both instruments will be performed to the volumetric samples. Gravimetric "grab" samples with determination of bulk density will provide an estimate of volumetric moisture content. Volumetric moisture derived from both the grab samples and moisture probes can then be compared.

Measurement Strategy:
On each flight overpass sampling day, two 0-5.6 cm gravimetric samples will be collected per field, one sample by each team member. This will be done using a bulk density core. The sample will be collected at two of the 16 sample points. Different sites will be selected each sample day, such that no site is sampled more than once. When the core is collected, three soil moisture probe measurements will be taken nearby where the core was extracted. The location of the core and probe measurements should both be taken between the crop rows, with the probe measurements within 15 cm of the location of the core. The probe readings will be recorded on data sheets.

Core samples will be placed in a plastic zip lock bag to minimize any moisture loss. Each bag should be labeled with a permanent marker, with the field, field-site number and the date. At the laboratory, the sample will be removed from the zip lock bag and immediately weighed. The wet weight is recorded and the sample is placed in a labeled container for oven drying. The sample is then oven dried for 24 hrs at 105^{o}C and re-weighed. To facilitate standardization and reduce errors, one individual will be assigned to weigh all samples.

Once the dry weight of the sample has been recorded, the sample will be kept for lab textural analysis.

4.1.2.2. Soil roughness

Objective: To measure both the root mean square (rms) roughness and roughness correlation length (ℓ) to assist with modeling of soil moisture from SAR backscatter, at the SMAP scale.

Measurement approach:
Data collected by Sherbrooke University in July 2008 has been used to assess the within and between field variability associated with surface roughness. This analysis determined that at this stage of the growing season (after planting and during crop growth) field to field variability in roughness was small. Within field variability was assumed to be even less than field to field variability. Tillage is the most significant driver of roughness and the same tillage implement is applied to an entire field. Small differences across a field can occur during tillage and erosion events due to variations in topography and soil properties. Based on these data, it was determined that roughness for the entire field could be characterized by measurements taken at two to three sites. However, replicates are still required to counter measurement errors and instrument precision. Consequently, 3 replicates will be taken at one site per field. The roughness team will take their measurements at the same locations as where biomass was sampled. This will reduce destruction to crops.

A 1-m long pin profilometer will be used to measure surface roughness. To adequately measure the correlation length, roughness measurements must be taken over long profiles (typically several metres). To achieve a longer 3-metre profile, once one profilometer measurement is taken, the instrument will be moved such that the end of the first measurement becomes the start of the second measurement. This is repeated a second time to achieve a 3-metre profile comprised of three 1-metre profiles. The three separate profiles are joined into a single profile using a matlab application, post data collection. This end-to-end approach will provide three 3-metre profiles at one site per field (table 6). In 2010, two teams of two were assigned to measure roughness.

The look direction of the airborne UAVSAR is not equivalent to the look direction of RADARSAT-2. It is important to characterize roughness in the same direction as the look direction of the SAR instruments, particularly if any macrostructure is present. Consequently the roughness profiles need to be taken parallel to the look direction of both the UAVSAR look direction, as well as the look direction of RADARSAT-2 (figure 18). Replicates will be taken approximately 5 m apart.

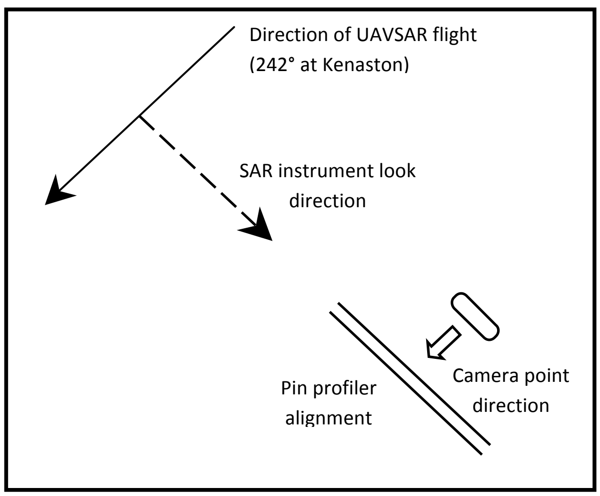

Figure 18. An example of the placement of the profilometer for a UAVSAR flight path at 242º.

The profilometer is a camera based method of capturing the roughness profile. Vegetation will interfere with the collection of these photos. Thus vegetation in front of the profile will be removed (or gently flattened by using a long piece of cardboard). Whenever possible, the profile will be located where the biomass team had removed the crop.

Surface roughness is expected to be quite stable through the campaign. Because this property is not highly variable in time (following seeding), roughness will be measured only twice on each field – at the beginning of the field campaign, and near the end of the campaign. Any changes in roughness due to field operations, including harvesting, as well as eroding of the soil will be captured with the second measurement.

A summary of the approach to measuring roughness is provided in table 6.

Table 6. Summary of surface roughness measurement strategy

	UAVSAR acquisitions	RADARSAT-2 acquisitions
Instrument	Needle profilometer	Needle profilometer
Number sites per field	2-3 (same site as RADARSAT-2)	2-3 (same site as UAVSAR)
Number of replicates per site	3	3
Distance between replicates	5 m	5 m
Number of profiles per replicate	3 (placed end-to-end)	3 (placed end-to-end)
Number of field visits	2 (at beginning and end of campaign)	2 (at beginning and end of campaign)

4.1.2.2. Vegetation properties for cropland

Objective: To measure biomass and canopy water content, and characteristics of the vegetation structure, to assess the effectiveness of vegetation parameterization associated with soil moisture retrieval models for both passive and active microwave sensors, at the SMAP scale.

Measurement approach:
A number of vegetation (VG) properties will be measured during SMAPVEX12. Some of these properties are static (measured only once). Others are dynamic (require repeated measurements). Characterization of the vegetation is an important aspect of the SMAPVEX12 campaign and the level of effort to collect these measurements and samples will be significant.

The variety of crops grown in southern Manitoba is substantial. The number of different crops to be sampled will be largely determined by the prevalence of each crop in the region, modified by access granted by the land owners. The focus should be placed on major crops. Major annual crops to be targeted will include spring wheat, canola, oats, barley, corn and soybeans. Some fields of perennial land cover, including grassland and tame hay (alfalfa and grass) will also be selected.

The following static and dynamic vegetation properties will be measured.

Static Properties
VG1: Plant Density
VG2: Row Spacing
VG3: Row Direction

Dynamic Properties
VG4: Leaf Area Index (LAI)
VG5: Biomass and Canopy Water Content
VG6: Height

VG7: Stem Diameter
VG8: Phenology
VG9: Crop Structure and Architecture
VG10 Canopy Reflectance

The sampling strategy will consist of collecting vegetation data at three sites per field, once per week. The change in vegetation structure, biomass and water content is significant during this period of peak growth and senescence, and thus weekly measurements are warranted. Sites will be selected based on historical knowledge of the variability in these fields, as well as knowledge gained by examining early season imagery. The location of these three sites will be stratified using this a prior knowledge with the goal to capture the mean field crop conditions as best as possible. Adjustments to the site locations may occur prior to the commencement of the campaign, but once these sites are established the locations will remain constant through the entire campaign. The location of these sites must also be easily accessible by the field crews.

The number of replicates required for each vegetation parameter will vary. These are detailed in table 7.

VG1: Plant Density
The density of plants will be determined by counting the number of emergent plants in a row, along a fixed distance (10 metres or 1 metre, depending on the crop type and planting density). This will be replicated for 10 rows. Counts will be recorded on data sheets. Row spacing measurements will also be required to calculate the density.

VG2: Row Spacing
Row spacing will be determined by measuring the distance between rows, for the 10 rows used to determine plant density. Row spacing should be measured at the soil level, with the distance measured being the distance between the centre of the plant from row one to the centre of the plant from row two. Row spacing will be recorded on data sheets.

VG3: Row Direction
The direction of planting will be recorded using a compass.

VG4: Leaf Area Index
LAI will be captured using hemispherical digital photos. Seven photos will be taken along two transects (14 photos in total) at three sites per field. These photos will be post-processed to estimates of LAI.

VG5: Biomass and Canopy Water Content
Vegetation biomass will be collected via destructive sampling. Canopy water content is derived from the biomass samples. One biomass sample will be collected per measurement site.

The approach to biomass sampling will be determined by the crop (planting approach and overall biomass). For crops with low to moderate biomass (field peas, for example) a 0.5 m x 0.5 metre square will be placed over the canopy. All above ground biomass will be collected by cutting all vegetation at the soil level. This approach is also well suited for crops which are broadcast seeded, or which have very dense planting (wheat, for example). For large biomass crops and those that have a row spacing wider than 0.5 m (corn and soybeans, for example), a different sampling approach will be taken. For these crops, 5 plants along three rows (15 plants in total) will be collected. Knowledge of the density of the crop will permit scaling of these measurements to a unit area (m^2).

Biomass collected via 0.5 m x 0.5 metre square: wheat, oats, barley, grassland and tame hay (alfalfa and grass)
Biomass collected via 5 plants along 3 rows: canola, corn and soybeans

Samples will be placed first in a paper bag, and then a plastic bag. The paper bag can be placed directly in the drying facilities (ovens or rooms), while the plastic bag minimizes water loss prior to weighing the wet sample. The paper bag must be labeled with the field and site number. Vegetation will degrade rapidly (within a few hours) and thus weighing of the wet sample must be completed quickly. Wet weights are taken with the paper and plastic bags (size of bags used and average bag weight must be recorded). Following wet weighing, plastic bags are removed and samples are placed in drying facilities for 72 hrs at 70 ^{o}C. The weight of the dry sample is then taken. To facilitate standardization and reduce errors, one individual will be assigned to weigh all samples.

When weeds are present within the sample site, the weeds will be placed into separate bags for weighing. The paper bag should be labeled with the field and site number, and also with the word “weeds”.

At the first sample site in each field, the crop sample will be segmented in the field. Paper bags should include an additional descriptive: heads, leaves, stems, seeds/pods/cobs as appropriate. The level of segmentation will depend on the crop.

Wheat, oats, barley – heads cut off to provide 2 samples (a) heads and (b) leaves+stems
Grassland and tame hay – no segmentation
Corn, canola and soybeans – leaves, seeds/pods/cobs and stems separated to provide 3 samples (a) leaves, (b) seeds/pods/cobs and (c) stems

VG6: Height
Crop height can vary significantly and increasing the number of measurements will help to improve the accuracy of the average crop height. In total 10 heights will be measured, 5 in each of two rows. The height will be measured to the top of the upper most part of the canopy, whether leaf or fruit. Leaves are to be left in their natural orientation, and not extended, for this measurement. Heights will be recorded on data sheets.

VG7: Stem Diameter
The diameter of the plant stem will be measured for the 10 plants used for height measurements. A simple caliper can be used. The diameter will be measured half way up the crop (at mid level). Stem diameters will be recorded on data sheets.

VG8: Plant Phenology
One lab technician will be responsible for weighing the wet and dry biomass samples. This individual will also be tasked with recording the phenology of each crop sample. This determination can take place during the weighing process and recorded on data sheets. The BBCH scale will be used.

VG9: Vegetation Structure and Architecture
The structure of the plant will be captured photographically. One photo will be taken in each field. A large piece of marker board, superimposed with a measurement grid, will be placed behind one crop row. A digital photo will be taken to record the overall plant structure.

In addition to this photograph, the geometry of the plant will be measured. This measurement protocol will be determined by Dr. Sab Kim.

Table 7. Summary of vegetation sampling strategies

Property	Number of sites per field	Replicates per site	Instrument	Temporal frequency	Description of approach	Assigned Team
Static Vegetation Parameters						
Plant Density	1	3		once	Count number of plants along 10 or 1 metre(s); replicate for 10 rows	AAFC students prior to campaign
Row Spacing	1	3	Meter stick/tape measure	once		AAFC students prior to campaign
Row Direction	1	1	Compass	once		AAFC students prior to campaign
Dynamic Vegetation Parameters						
Leaf Area Index	3	1	Camera and fish eye lense	once per week	7 photos taken along 2 transects (14 in total)	Biomass
Biomass and Canopy Water Content	3	1	0.5 x 0.5 m square	once per week	For wheat, oats, barley, grassland, tame hay collect all biomass within square; For canola, corn, soybeans collect five plants along each of 3 rows (15 in total)	Biomass
Height	3	10 plants	Meter stick/tape measure	once per week		Biomass
Stem Diameter	3	10 plants	calliper	once per week		Biomass
Phenology	1	1		once per week		Lab Tech
Canopy structure	1	1	Digital camera and gridded board	once per week	Gridded marker board is placed behind one row and photo taken.	Structure
Canopy architecture	1	1				Structure
Canopy reflectance	3	5	CropScan	once per week	Measure every metre over 5 metre distance, diagonally across rows.	Biomass

4.1.2.3. Multi-spectral scans

Objective: To characterize the general crop condition and growth state as a function of the reflectance in a number of optical and infrared wavelengths.

Measurement approach:
A CropScan multi-spectral instrument will be used to capture reflectance of the crop canopy. These reflectance data will be collected at each vegetation sample site just prior to removal of the biomass. Above canopy readings will be recorded every meter for 5 meters, moving in a diagonal across row direction. Five replicates will be taken at each site. Replicates will be located about 1 metre apart. This sampling scheme will yield 25 reflectance measurements per site.

4.1.3. Aircraft campaigns (flight lines)

(Tom to complete)

4.2. Satellite data coverages

(To be completed)

Appendix – Ground Measurement Protocols

A.1. Field Protocols, general overview on daily activities

General overview on daily activities

Departure from base to field	5:30 a.m.
Arrival at site and start sampling ○ **5 fields per team per overpass** ○ **Estimate is 40 minutes sampling per field with 30 minutes travel time**	7:00 a.m.
Overpass time	6:00 a.m.
End of sampling and start to base	12:30 p.m.
End of day time and activities	2:00 p.m. ○ Truck cleanup and organization for next day ○ Data sheets photocopied and filed ○ Data entry and archiving ○ Data plots to central data committee. ○ Pass soil and biomass samples to lab technician for weighing
Debriefing meeting	4:00 p.m.

Data inspection for data review meetings	On down days we should be looking at our data and interfacing with other teams

A.2. Soil Moisture measurements

(Aaron to complete)

A.2.1. Soil moisture probe instructions
A.2.2. Data Sheets for Soil Moisture
A.2.3. Data Sheets for intensive soil moisture survey days

A.3. Soil Roughness

(Ramata to complete)

A.3.1. Soil Roughness Instruction
A.3.2. Soil Roughness Datasheet

A.4 Vegetation

A.4.1 Vegetation Sampling Protocols

VG1: Plant Spacing

Plant spacing will be determined by counting the number of plants which have emerged in a single row, over a specified distance, replicated 10 times.

1. Wider-spaced row crops (corn, soybeans, sunflower, canola….)

- Use a tape measure and flag a distance of 10 metres along one row (tie flagging tape to first and last plant, or use field flags to delineate first and last plant)
- For each of 10 consecutive rows, count the number of plants along the 10 m distance.
- Record each value on the data sheet.

2. Narrow-spaced row crops (wheat, barley, oats…)

- Use a tape measure to flag a distance of 1 metre along one row (tie flagging tape to first and last plant, or use field flags to delineate first and last plant)
- For each of 10 consecutive rows, count the number of plants along the 1 metre distance.
- Record each value on the data sheet.

**Timing: Plant spacing should be completed prior to commencement of field campaign. This task will be easier when crops are just past emergence, particularly for narrow-spaced crops.

VG2: Row Spacing

Row spacing will be determined by measuring the distance between rows replicated for 10 rows.

- Use a tape measure to record the row spacing for each of the 10 rows used to determine the plant density.
- Measurements are to be taken at the soil level, as the distance between the centre of the plant in row one to the centre of the plant in row two.
- The first measurement will be taken between the first row to the second row
- The last measurement will be taken between the 10th row to the 11th row (a row in which the plants are not counted) for a total of 10 row widths.
- Record each row spacing value on the data sheet.

Plant density (PD) will be calculated as follows:

$$Plant\ Density\ {*}PD{+}= \frac{Sum\ of\ \ Plants\ in\, 32\ Rows\ x\, 32m\ Area}{\left(Average\ Row\, Width\ over\, 32\ Rows\right)\times 32m} = \frac{Average\ \%Plants}{m^4}$$

VG4: Leaf Area Index (LAI)

Seven hemispherical photos will be taken every 5 metres, along two parallel transects. Thus for each site, a total of 14 photos are taken.

- The camera lens should be a minimum of 1 metre above the highest point of the canopy (when photos are taken downward) or 1 metre below the lowest leaf of the canopy (when photos are taken upward)
- Based on crop height and this minimum required distance, decide if photos will be taken downward or upward. Record this orientation (downward or upward) on the data sheet.
- In the case of row crops, photos will be taken in the middle of the crop row.
- In the case of downward photos, hold camera pointed downward, out at chest height and level. In the case of upward photos, place camera on ground and pointed upward.
- Take the first photo. Take photos 2-7 at 5 metre increments along first transect.
- Cross over to second row, and take photos 8-14 at 5 metre increments along this second transect.
- When walking back on this second transect, be sure to offset the location of photos as shown in Figure 7.
- When taking the photo, the operator should always face the sun.
- Record the photo numbers on the data sheet.
- Mark the sun direction on the data sheet.

Camera setup:
1) Exposure Mode set to P (programmed).
2) Frame Release Mode (top left dial of body) set to Single.
3) Auto Focus Mode (front of body) set to Manual.
4) Metering (top right) set to Matrix.
5) AF Area Mode set to Matrix.
6) Image format (using menu) set to NEW RAW HIGH + JPEG fine.

7) Image quality (using menu) set to 14 bit.
8) White balance (using menu) set to sun or shadow.
9) Active D Lighting (using menu) set to Auto.
10) Hand held (using menu) set.
11) Noise reduction (using menu) set to hand held.
12) Image display (using menu) set to histogram + details.
13) Set local time (using menu)

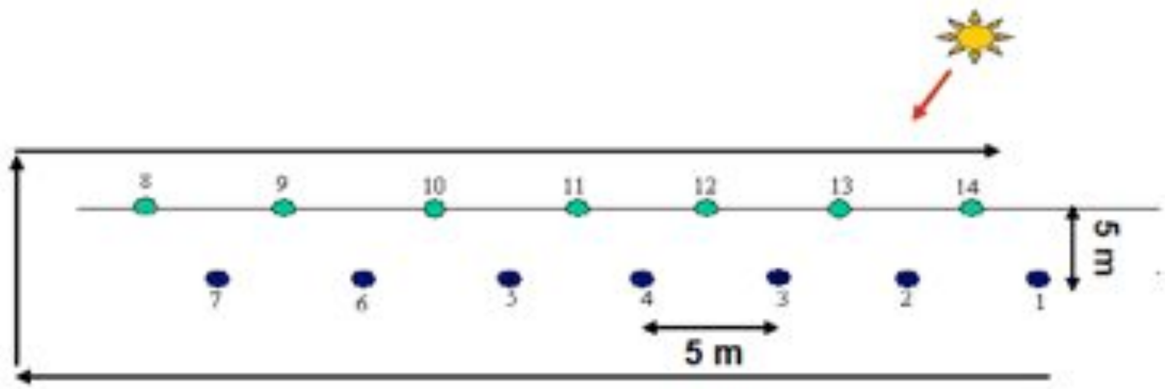

Figure 19. Sampling transect for hemispherical photos to measure LAI

VG5: Biomass and Canopy Water Content

1. Wider-spaced row crops (corn, soybeans, sunflower, canola….)

For larger biomass and wide-spaced row crops, biomass will be determined on a per plant basis and scaled to total biomass using the plant density calculations. At each sample location, 15 plants (total) will be harvested from 3 consecutive rows (5 plants x 3 rows).

- With a knife, cut the crop at the base of each plant. Do not include residue or weeds in the sample.
- Place the crop in a labeled paper biomass bag. The top of the bag can simply be rolled down. Then place the paper bag inside a labeled plastic bag. Secure the plastic bag with a firm knot.
- The paper bag should be labeled as follows:

Field # - Site #
Date

- If the plants are large, it may be necessary to use more than one paper bag. In this case, place each paper bag inside a separate plastic bag and add the following additional label to the paper bag

Sample x of y (for example: sample 2 of 3)

- If the plants are wet with dew, gently shake the vegetation prior to bagging.

- If weeds are present, cut weeds at ground level and place in a separate paper bag. Then place the paper bag inside a labeled plastic bag. Secure the plastic bag with a firm knot. Label the paper bag as follows:

Field # - Site # - Weeds
Date

- For site 1 of each field, the crop sample will be segmented in the field. The level of segmentation will depend on the crop.

Wheat, oats, barley – heads cut off to provide 2 samples (a) heads and (b) leaves+stems
Grassland and tame hay – no segmentation
Corn, canola and soybeans – leaves, seeds/pods/cobs and stems separated to provide 3 samples (a) leaves, (b) seeds/pods/cobs and (c) stems

- Paper bags should include an additional descriptive: heads, leaves, stems, seeds/pods/cobs as appropriate. For example,

Field # - Site 1 - leaves
Date

2. Narrow-spaced row crops (wheat, barley, oats…)

For low biomass and narrow-spaced row crops, biomass will be collected from within a standardized 0.5 m x 0.5 m area, using a quadrat. At each sample site, 3 replicates will be gathered.

- Place the quadrat over the top of the crop.
- With a knife, cut all plants within the quadrat, at the base of each plant. Do not include residue or weeds in the sample.
- Place the crop in a labeled paper bag. The top of the bag can simply be rolled down. Then place the paper bag inside a labeled plastic bag. Secure the plastic bag with a firm knot.
- The paper bag should be labeled as follows:

Field # - Site #
Date

- If the plants are wet with dew, gently shake the vegetation prior to bagging.

- If weeds are present, cut weeds at ground level and place in a separate paper bag. Then place the paper bag inside a labeled plastic bag. Secure the plastic bag with a firm knot. Label the paper bag as follows:

Field # - Site # - Weeds
Date

- For site 1 of each field, the crop sample will be segmented in the field. The level of segmentation will depend on the crop.

Wheat, oats, barley – heads cut off to provide 2 samples (a) heads and (b) leaves+stems

Grassland and tame hay – no segmentation
Corn, canola and soybeans – leaves, seeds/pods/cobs and stems separated to provide 3 samples (a) leaves, (b) seeds/pods/cobs and (c) stems

- Paper bags should include an additional descriptive: heads, leaves, stems, seeds/pods/cobs as appropriate. For example,

Field # - Site 1 - leaves
Date

- If the plants are large, it may be necessary to use more than one paper bag. In this case, place each paper bag inside a separate plastic bag and add the following additional label to the paper bag

Sample x of y (for example: sample 2 of 3)

3. Lab procedures and calculation of biomass and canopy water content

The plant samples are to be returned to the lab where wet and dry biomass weights will be determined. Canopy water content will be derived from these weights. One individual will be tasked with weighing and drying all the samples.

Wet weights should be taken as soon after biomass collection as possible, as plant matter can degrade quickly. To slow this process, keep samples in a cool shaded place or a cooler if possible until samples can be weighed.

- Tare (zero) lab scale.
- Leave plant sample in paper and plastic bag. Place sample on scale and record weight in grams.
- If plant sample is too large for the scale a larger flat surface (pan, cardboard) can be placed on the scale before it is zeroed.
- Determine the size of plastic bag used and weigh 10 plastic bags. Record the weight of these 10 bags.
- Remove plastic bag and place paper bag in the drying ovens or drying room. If ovens are not immediately available, store samples in a cool place (cooler/fridge) to minimize decomposition.
- Dry at about 105^{o}C for 72 hours.
- Before re-weighing crop samples, verify that sample has been completely dried. If uncertain, place crop sample back in oven until re-weighing establishes that dry weight is constant.
- Tare (zero) lab scale.
- Leave plant sample in paper bag. Place sample on scale and record weight in grams.

Plant water content (PWC) will be calculated as:

$$Plant\ Water\ Content\ *PWC+*g+ = \left[Wet\ Weight\ *g+ - \ plastic\ bag\ weight\ *g+\right] - Dry\ Weight\ *g+$$

For wider spaced row crops (corn, soybeans, sunflower, canola etc.) plant water content will be scaled to an area basis (grams of water per m^2) according to:

$$Area\ PWC\ *gm^{-4}+= \frac{*PWC+*g+}{Number\ of\ \ plants\ collected}\ x\ PD\ *plants\ \ per\ m^4+$$

Narrow spaced low biomass crops are already collected on an area basis (0.25 m^2). Thus the total plant water content is easily scaled to g/m^{-2} by applying a factor of 4.

VG6: Height

The plant height of ten plants will be recorded at each site.

- Use a tape measure to measure the distance from the soil to the highest point of the plant. Do not extend leaves. Leaves should remain in their naturally occurring position/orientation during measurement.
- Take 5 height measurements in one row. The second set of 5 measurements should be taken in the adjacent row.
- Record all 10 measurements on the data sheet.

VG7: Stem Diameter

Stem diameter will be measured for the same 10 plants used for crop height.

- Use a caliper to measure the diameter of the stem, half way between the top of the crop and the soil.
- Record all 10 measurements on the data sheet.

VG8: Plant Phenology

Plant phenology will be determined by the lab technician charged with weighing the samples.

- After weighing the sample for site 2, take crop out of bag.
- Refer to the BBCH scale and determine the crop growth stage. Record this on the data sheet.
- Place crop sample back into paper back and place in drying oven/room

VG9: Vegetation Structure and Architecture

The structure of the plant will be captured photographically.

- Place the gridded marker board behind a row of crops.

- It will be necessary to either gently flatten the plants in front of the row to be photographed, or to take the picture where the biomass has been removed.
- Write the Field # - Site # and date on the gridded marker board.
- Take the photo. Check that photo is good (illumination, focus etc.).

A.4.2 Vegetation Sampling Data Sheets

A.4.3 Vegetation Sampling Teams*

Table 8. Summary of vegetation sampling teams

	Number of people required	Source of Personnel	Frequency	Timing	Notes
Plant Density	2	Students hired in MB	once	Before field campaign commences	Should be completed just after emergence so that ID of individual plants is easier
Row Spacing	2	Students hired in MB	once	Before field campaign commences	Should be completed just after emergence so row measurement is easier
Row Direction	2	Students hired in MB	once	Before field campaign commences	
Crop Structure and Architecture	2 (1 team of 2)		Each field visited once per week		Led by Dr. Sab Kim
Biomass, Height, Stem Diameter, LAI, Crop Scan	12 (3 teams of 4) *1 - LAI* *1 - biomass* *1 - cropscan* *1 - notes and photos*		Each field visited once per week		Each team visits 4 fields per day; assume 4 work days/week (16 fields per week per team). Other days are rain days, down days or helping with soil moisture)
Phenology	1	Lab Tech			Done at time of biomass weighing
Soil moisture	20 (10 teams of 2)		Every airborne acquisition		Each team visits 4-5 fields per day.
Sample weighing	1	Lab Tech			

* assumes 45 fields

A.4.4. Multispectral sampling instruction, step by step protocol

Reflectance data will be collected for each vegetation sampling location (see figure 20) just prior to removal using the following sampling scheme.

- Hold the radiometer so that it is well above the plant canopy
- Take a reading
- Move up 5 meters and take another reading until you have completed 5 readings
- Move over 1 meter in the case of row crops (corn, soybeans, canola), to the next row
- Take another 5 above canopy readings
- Repeat until you have completed 5 transects, and thus a total of 25 readings (5 readings over 5 transects)

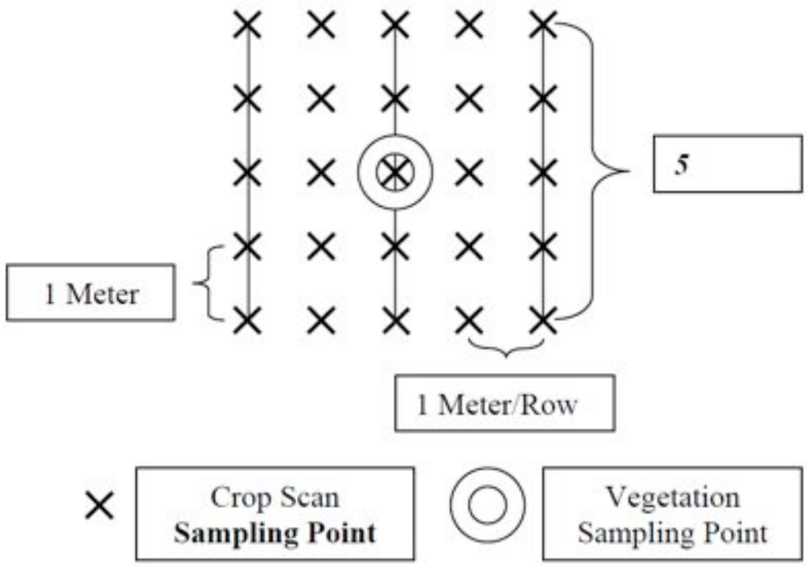

Figure 20. Crop scan measurement protocol

A.4.5. Multispectral datasheets